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A HYBRID CERAMIC-POLYMER COMPOSITE T.P.S. FOR MULTIPLE ATMOSPHERIC ENTRY PROBES

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THERMAL PROTECTION SYSTEMS FOR MULTIPE ATMOSPHERIC ENTRY SPACECRAFT AND PROBES

General Specification Aims

- TPS must thermally and mechanically protect the internal systems of the craft
- Low density to maximize payload
- Withstand the very high heat-fluxes at the shock-wave front and at the wake zone
- Withstand micro-meteorite impact as well as other mechanical impacts without spalling or loss in mechanical integrity
- Be re-usable for at least a few atmospheric entries even in oxidising atmospheres

Current Thermal Protection Systems

Ablative TPS

- Phenolic polymer reinforced with chopped glass fibres
- Developed in the 1960s for the Apollo flights
- Dissipates heat by ablation of polymer: “Active TPS”
- Low density but propensity to spalling after charring
- Can only be used reliably once
- Low mechanical strength and impact strength

Ceramic TPS

- Fibre toughened C/C
- “Passive TPS”
- Used for the HT regions of the space-shuttle and ICBMs
- Insufficient heat-flux resistance for atmospheric entry probes
- Mainly for non-oxidising atmospheres
- Higher density than ablative TPS

Limited reliability for multiple entries

A HYBRID T.P.S. SOLUTION?

Conceptually a **win-win** situation:

- A HT porous ceramic matrix filled with ablative reinforced filler, covered by a 2-D SiC/SiC fibre-toughened surface layer.
- Multi-composite structure offering significant synergies:
  1. Ablator dissipates heat, reducing heat load on ceramic
  2. Ceramic mechanically “shields” ablator, reducing its rate of ablation and protecting it from spalling and loss of material, even after extensive fracture.
  3. Ablator filler enhanced heat-distribution in the ceramic
- Low overall density of system (<2g/cm3)
- 2-D surface layer helps to conduct heat away from nose due to its highly anisotropic thermal conductivity (40 times more along surface than across the thickness)

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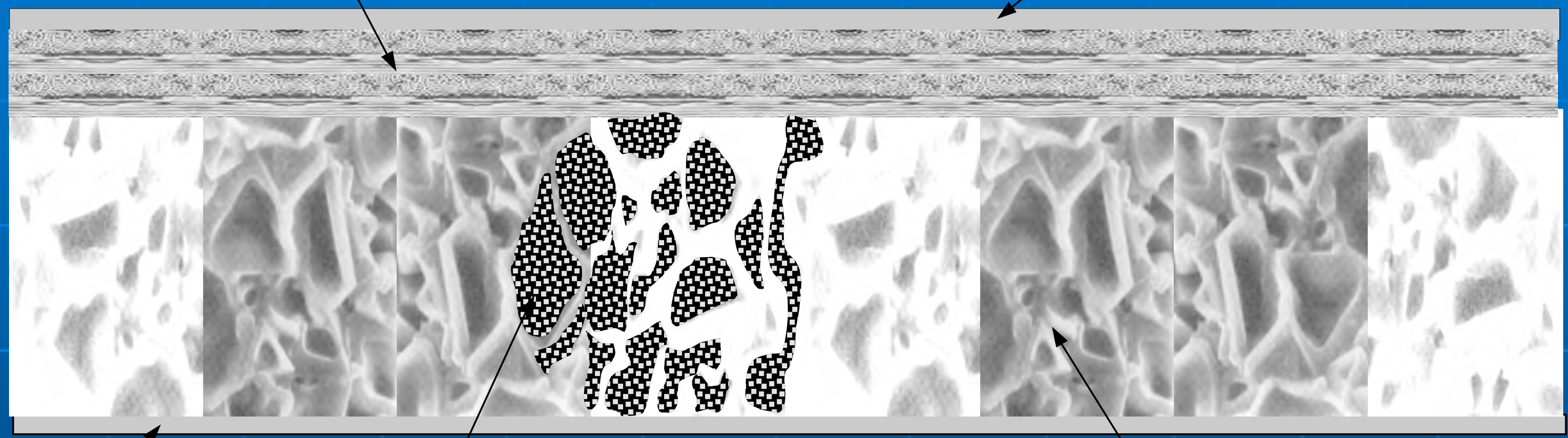
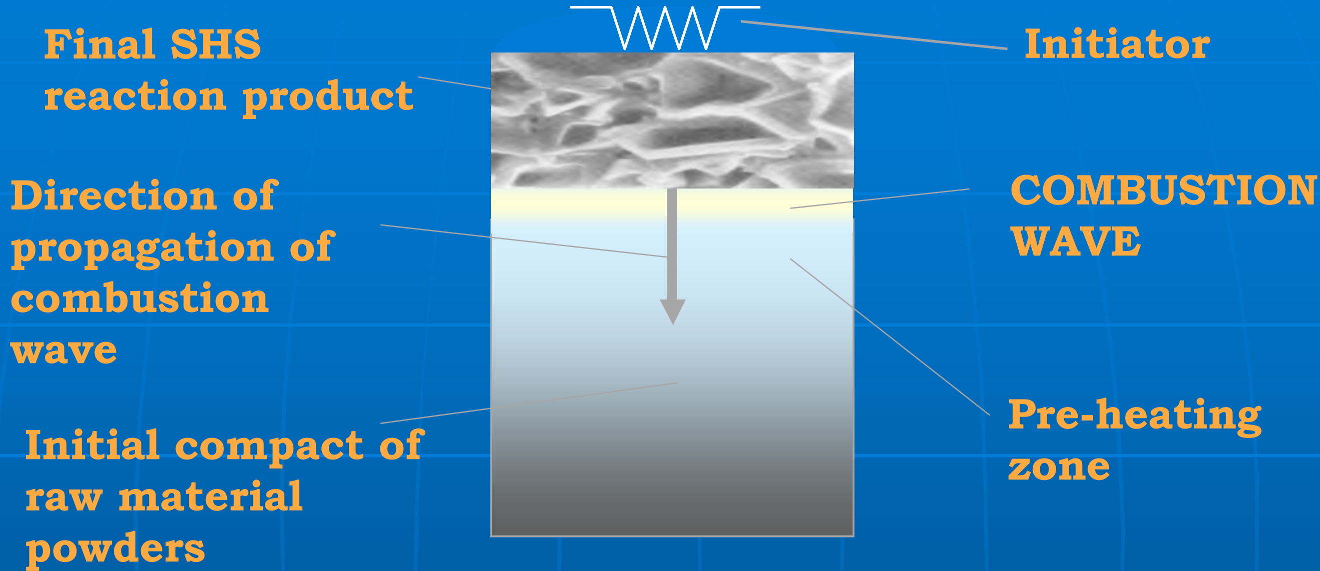
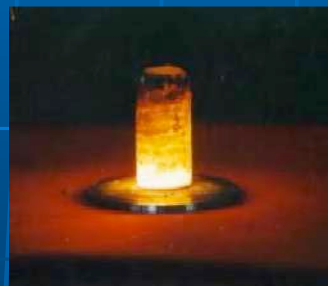

Low density fibrous 2-D high-toughness anisotropic SiC/SiC composite
Hard nano-structured ceramic coating – Plasma or PVD
OUTER SURFACE
INNER SURFACE
Metallic substrate with attachments
ABLATIVE chopped-fibre reinforced phenolic filler polymerized in –situ by _-radiation or catalytically
Low density HT refractory with large pores made by SHS

The Self-Propagating High-Temperature Combustion Synthesis process (SHS)



Initiation



Completion

- *Nett-shape exothermic synthesis*
- *Very high temperature refractories with strong structure*

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MAIN INNOVATIONS:

- **$MgO/MgAl_2O_4$ low density refractory base made by nett-shape SHS (rapid combustion synthesis):**
  - T_{use} > 2200°C
  - Thermal conductivity < 1.0 W/mK
  - Bending strength > 100 MPa
  - Compressive (crushing) strength > 300MPa
  - Density <1g/cm3)

- **In-situ polymerized chopped SiC fibre-toughened ABLATIVE filler for the porous refractory working offering synergy**

  - Refractory partially “shields” the ablative filler, reducing ablation, eliminating spalling and increasing life.
  - SiC chopped fibre enhanced heat distribution within the ablator and the refractory ceramic and increases ablator strength and toughness.

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MAIN INNOVATIONS (continued):

- 2-D SiC/SiC high toughness layer:
  - T_{use} > 2600°C (in non-oxide atmospheres) or > 1700 °C in oxidizing atmospheres
  - High resistance to mechanical impact
  - Thermal conductivity: longitudinal > 40 W/mK, transverse < 1.0W/mK
  - Toughness > 25MPam$^{1/2}$
  - Bending strength > 300 MPa
- Hard, nano-structured, low-cost coating by PVD or Plasma
  - Enhanced impact strength and overall integrity
  - Bonding of layers by in-situ SHS

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EXPECTED CHARACTERISTICS:

- High lateral heat conduction and dissipation due to the high longitudinal thermal conductivity of SiC fibres, thereby reducing the cumulative thermal load on the TPS
- High toughness and crack-resistance due to the contribution of tough fibrous SiC/SiC under the thin coating. Even if a crack initiates at the SiC skin, it will be stopped very efficiently by the SiC/SiC thereby offering high mechanical reliability.
- Heat energy dissipation by the shielded ablator without spalling or loss of insulation
- Satisfactory thermal insulation across the thickness – the thermal conductivity is expected to be significantly less than 1W/mK across the thickness of the system.
- High overall rigidity and mechanical strength due to the innovative SHS bonding between the elements.

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DEVELOPMENTS NEEDED:

- Optimization of the MgO-based SHS refractory with and without nano-structuring. Although the constituent materials have been developed in the past for aerospace, further development and optimization is needed.
- Optimisation of chopped SiC-fibre-filled monomer infiltration of ceramic refractory and in-situ polymerisation by _-irradiation.
- Optimization of SHS bonding between the SiC/SiC layer and the MgO refractory layer and with the latter to the thin metallic alloy substrate to ensure high mechanical strength and integrity
- Optimization of coating techniques for the application of the outermost layer – EPD, PVD and Plasma
- Development and optimization of attachment techniques onto the body of the probe shield or craft.
- Testing in ARC jet installation and further optimisation